Document made available under the Patent Cooperation Treaty (PCT)

International application number: PCT/AU05/000296

International filing date: 02 March 2005 (02.03.2005)

Document type: Certified copy of priority document

Document details: Country/Office: AU
Number: 2004902978
Filing date: 03 June 2004 (03.06.2004)

Date of receipt at the International Bureau: 22 March 2005 (22.03.2005)

Remark: Priority document submitted or transmitted to the International Bureau in compliance with Rule 17.1(a) or (b)

World Intellectual Property Organization (WIPO) - Geneva, Switzerland
Organisation Mondiale de la Propriété Intellectuelle (OMPI) - Genève, Suisse

PCT/AU2005/000296

Australian Government

Patent Office
Canberra

I, LEANNE MYNOTT, MANAGER EXAMINATION SUPPORT AND SALES hereby certify that annexed is a true copy of the Provisional specification in connection with Application No. 2004902978 for a patent by QUCOR PTY LTD as filed on 03 June 2004.

COMMONWEALTH OF AUSTRALIA
AUSTRALIA
PATENT OFFICE

WITNESS my hand this
Fourteenth day of March 2005

LEANNE MYNOTT
MANAGER EXAMINATION SUPPORT
AND SALES

AUSTRALIA

Patents Act 1990

PROVISIONAL SPECIFICATION

Applicant(s):

QUCOR PTY LTD

Invention Title:

A PHOTON SOURCE

The invention is described in the following statement:

A PHOTON SOURCE

Field of the Invention

The present invention broadly relates to a photon source and relates particularly, though not exclusively, to a source of single photons suitable for quantum key distribution.

Background of the Invention

For many applications, such as a quantum key distribution, photon sources are required that provide single photons. For example, colour centres in diamond could be used for single photon emission. Such colour centres typically comprise at least one optically active impurity atom, such as a nitrogen atom, which is positioned adjacent to a vacancy in the diamond matrix. Such nitrogen-vacancy (N-V) centres are excited using an optical or electronic excitation source and single nitrogen-vacancy $(N\text{-}V)^-$ colour centres, for example, emit single photons having a wavelength in the vicinity of 637nm. However, the single photons are emitted isotropically, which makes the collection and guiding of the emitted photons very difficult. Usually an objective lens, accurately aligned to a single colour centre, is used to collect the emitted photons, but optical losses at optical interfaces can be significant and this collection technique is generally cumbersome and not very robust. Further, optical lenses are difficult to combine with integrated technology and also make cooling or heating of the device more difficult.

Quantum key distribution is a quantum cryptography technique which requires a source of single photons. However, the implementation of quantum key distribution is

difficult as the generation of single photons using a suitable source is a challenge.

Summary of the Invention

The present invention provides in a first aspect a photon source comprising:

an optical waveguide and

a material comprising at least one colour centre, the or each colour centre being arranged for emission of single photons and the material having been grown so that the material is bonded to the optical waveguide and in use at least some of the single photons emitted by the or each colour centre are guided by the optical waveguide.

The present invention provides in a second aspect a photon source comprising:

an optical waveguide incorporating a material having at least one colour centre arranged for emission of single photons, the material being incorporated so that in use at least some of the single photons emitted from the or each colour centre are guided by the optical waveguide.

Throughout this specification, the term "colour centre" is used for any optically active atomic, molecular or vacancy centre from which single photons may be emitted including atomic or molecular centres which are arranged for emission of single photons having wavelengths inside or outside the visible range.

In the first and second aspects of the invention the material typically has a diamond structure. In specific embodiments of the invention, the material is a diamond material such as a synthetic diamond material which may take the form of a diamond crystal.

The waveguide typically has a core region and the material typically is grown on a portion of the core region of the waveguide.

In the photon source according to the first or the second aspects of the invention the material may be indirectly bonded to the waveguide. For example, a layer of another material may be positioned between the material and the optical waveguide. However, the material typically is directly bonded to the waveguide.

In the photon source according to the second aspect of the invention the material may be embedded in the optical waveguide. The material may also be a part of the waveguide. For example, the material may comprise a core portion or the entire core may be composed of the material. In one specific embodiment the waveguide comprises a core that is composed of the material, such as diamond, and the or each colour centre is formed in the core of the waveguide. For example, the diamond core may be formed first and the or each colour centre may be generated in the diamond core (eg by implantation).

Because the material is bonded to the waveguide and/or the material is incorporated in the optical waveguide, the or each colour centre is coupled to the waveguide. Consequently the photon source according to the first or second aspect has the advantage that no further optical components are required to direct the emitted single photons to the waveguide.

Further, the photon source may be relatively robust and small, may be integrated and is relatively easy to cool or heat. In addition, a close association of the colour centre with the waveguide is beneficial for the efficiency of the photon source as colour centres are often isotropic photon emitters. The coupling of the or

each colour centre with the waveguide may also result in improved stability and durability of the photon source.

The or each colour centre in the photon source according to the first or second aspect of the invention typically comprises an impurity or impurities in the diamond material. For example, the or each impurity may be a nitrogen atom positioned adjacent a vacancy such that a nitrogen-vacancy (N-V) colour centre is formed. The or each impurity may also be a nickel atom positioned adjacent four nitrogen atoms so that a so-called "NE8" colour centre is formed.

In a specific embodiment the photon source according to the first or second aspect of the invention is a source of single photons such as a source that does not simultaneously emit two or more photons. In this case the photon source typically comprises one colour centre for the emission of single photons.

In the first and second aspects of the invention the waveguide may be provided in any form that is arranged to guide photons. For example, the waveguide may be an optical fibre. Alternatively, the waveguide may be a planar waveguide. In either case the waveguide may comprise a core region that typically is surrounded by a core-surrounding region which has a lower refractive index than the core region. In one specific embodiment the waveguide comprises a diamond core in which the or each colour centre is formed.

Alternatively or additionally, the waveguide may comprise a number of light-confining elements, such as tubular portions that may be hollow. The light-confining elements may be arranged about the core region so that light can be guided in the core region. The core region may be solid and the light-confining elements may result

in an average refractive index of a core-surrounding region being lower than of the core region.

The light-confining elements may also be arranged so that a photonic crystal waveguide is formed having photonic bandgap in the core-surrounding region. In this case the core may be hollow or may comprise defects or impurities that locally destroy the photonic bandgap and thereby enable guiding of photons in the core region.

In specific embodiments of the first and second aspect of the invention the material is positioned in a cavity which is located in the waveguide, typically in or adjacent a core region of the waveguide. The cavity typically is an optical cavity and may be partially hollow or may at least in part be filled with a material that has a different refractive index than the core region. In this case the photon emission of the or each colour centre may be less isotropic and photons may be preferentially emitted into an enhanced cavity mode. Consequently, the optical cavity may improve the efficiency of the photon source.

The present invention provides in a fourth aspect a method of fabricating a photon source comprising:

providing an optical waveguide and

growing a material on adjacent or in association with the optical waveguide in a manner so that at least one colour centre is formed in the material for emission of single photons.

The material typically is grown in a manner such that the material is bonded to the optical waveguide and in use at least some of the single photons emitted from the or each colour centre are guided by the optical waveguide.

The material typically is grown so that the material is directly bonded to the waveguide. Alternatively, the material may be grown so that the material is indirectly bonded to the optical waveguide and a layer is positioned between the optical waveguide and the material.

The optical waveguide may be any type of optical waveguide including any type of planar waveguide and optical fibres. For example, the optical waveguide may comprise a core region that is surrounded by a core-surrounding region which has a lower refractive index than the core region.

Alternatively or additionally, the optical waveguide may comprise a number of light-confining elements, such as tubular portions, that are arranged about the core region. The light-confining elements may also be arranged so that a photonic crystal waveguide is formed having photonic bandgap in the core-surrounding region.

The method may comprise the additional step of forming at least one recess in the optical waveguide. For example, the waveguide may be elongated and have a core and a core surrounding region and at least one recess may be formed at an end-face of the waveguide in the core region. The or each recess typically is etched in the core region using an etch-process that preferentially etches material of the core region.

The material may comprise diamond crystals having the or each colour centre. The step of growing the material typically involves chemical vapour deposition (CVD). The step of growing may also comprise growing the material in the or each recess, for example at an edge associated with the or each recess. The inventors have observed that favourable growth of the material often occurs at the or each edge associated with the or each recess. The or each

edge typically is at or near the core region and therefore the or each recess has the advantage that the diamond crystals predominantly grow at or near the core region.

If material is grown at an end-face of the waveguide, the method may comprise the step of splicing (fusion or otherwise) the end-face with an end-face of another waveguide. In a specific embodiment the material is grown at an end-face and in the or each recess and the method comprises the step of fusing the end-face with an end-face of another waveguide so that the or each recess is closed and forms a cavity embedding the material having the or each colour centre. In this case the material typically comprises one colour centre.

In a specific embodiment the photon source is fabricated so that the photon source comprises only one particular colour centre in the light guiding region. After the formation of the colour centre, the colour centre may be activated using a suitable excitation source such as suitable laser radiation or electrons. The method may also comprise the step of analysing if only one colour centre is present in the photon source by analysing the photons emitted from the or each colour centre.

The present invention provides in a fifth aspect a a method of fabricating a photon source comprising an optical waveguide, the method comprising the steps of:

fabricating an optical waveguide incorporating a material in which at least one colour centre for the emission of single photons can be formed and

forming the or each colour centre in the material in a manner so that in use at least some of the single photons emitted by the or each colour centre are guided by the optical waveguide.

The material may be embedded in another portion of the optical waveguide.

The optical waveguide may have a core and the material forms a part of the core. The core may also be composed of the material.

The present invention provides in a sixth aspect a photon source fabricated by the above-defined method.

The present invention provides in a seventh aspect a quantum key distribution system comprising the photon source according to the first aspect of the invention.

Because the material is bonded to and/or incorporated in the waveguide and the or each colour centre is coupled to the waveguide, the quantum key distribution system comprising the above-defined photon source may be of improved practicality and efficiency.

The invention will be more fully understood from the following description of specific embodiments of the invention. The description is provided with reference to the accompanying drawings.

Brief Description of the Drawings

Figure 1 (a) and (b) shows schematic cross-sectional representations of photon sources according to embodiments of the present invention,

Figure 2 (a) and (b) shows scanning electron micrographs of photon sources according to other embodiments of the present invention,

Figure 3 shows a diagram illustrating the fabrication of a photon source according to a further embodiment of

the present invention,

Figure 4 shows a schematic representation of a photon source during fabrication according to yet another embodiment of the invention, and

Figure 5 shows a schematic representation of a quantum key distribution system according to another embodiment of the invention.

Detailed Description of Specific Embodiments

Referring initially to Figure 1 (a), a photon source 10 according to a specific embodiment of the present invention is now described. The photon source 10 comprises an optical waveguide 12 having a core 14 and a cladding 16. In this embodiment that cladding 16 comprises a material that has a refractive index lower than that of the core 14. A diamond crystal 18 is embedded in the core 14. The diamond crystal 18 comprises a colour centre which in use emits single photons. In this embodiment, the colour centre comprises a vacancy in the lattice of the diamond crystal and an adjacent nitrogen atom that replaces another carbon atom so that a nitrogen-vacancy $(NV)^-$ centre is formed. In use, laser radiation, for example having a wavelength of 514 nm or 532nm, is used to excite the colour centre and the decay of the excited state results in the emission of a single photon.

In this embodiment, the diamond crystal is embedded in the core 14 of the waveguide 12. Figure 1 (b) shows a variation of this embodiment. The shown photon source 20 comprises a crystal 18 that is grown on end-face 22. In both cases the colour centre is coupled to the waveguide and no further optical components are required to direct the emitted single photons into the waveguide. Further, the close association of the colour centre with the

waveguide may result in a larger proportion of the photons being guided by the waveguide and therefore in increased efficiency of the photon source.

In this embodiment the core 14 is composed of germanium doped silica and the cladding 16 is composed of silica. It is to be appreciated that the waveguide 12 may in variations of this embodiment be provided in form of any type of waveguide. Both, optical fibres and planar waveguides may be used. For example, in an alternative embodiment the waveguide may comprise a number of light-confining elements, such as tubular portions that may be hollow and that may be arranged around a core region. The light-confining elements may also be arranged so that a photonic crystal waveguide is formed having a photonic bandgap in the core-surrounding region.

Figure 2(a) shows a scanning electron microscopy micrograph. The micrograph shows end-faces of optical fibres 30 on which diamond crystals 31 with colour centres are grown. Figure 2(b) shows a scanning electron micrograph of the diamond crystals 31 on a fibre end-face with a larger magnification. The concentric rings visible in the SEM image are due to etching of the doped depressed cladding region that surrounds the core region. Two single crystals in the centre of these rings are located directly over the core region.

Figure 3 illustrates the fabrication of a photon source according to an embodiment of the present invention. In this fabrication process diamond crystals having the colour centres are grown on end-faces of optical waveguides (optical fibres or planar waveguides). The end-faces with diamond crystals are then fused with end-faces of bare waveguides thus embedding respective diamond crystals with respective colour centres in

respective fused fibre cores. A 514 or 532 nm laser source is coupled into the fibre and the radiation excites the single $(N\text{-}V)^-$ colour centre resulting in emission of a photon in the vicinity of 637 nm from the colour centre. Excitation may also be achieved by incidence of the pump source on the waveguide at 90 degrees to the direction of propagation, proximate to the colour centre. This has the added advantage of preventing the pump wavelength from travelling down the waveguide. Should the pump wavelength need to be removed from the waveguide, a Bragg grating would be used in the device or external to the device.

If the waveguides are optical fibres, initially the optical fibres are stripped and cleaved to form high quality end-faces. Bundles of the cleaved fibres are assembled and secured in a tantalum (or other suitably non-reactive material) tube and may be ultrasonically scratched with a diamond powder containing alcohol suspension. These procedures act to produce diamond nucleation sites or seeds which promote diamond growth (steps 32 (a) and (b)). The fibres (or planar waveguides) are then cleaned and mounted in a sample holder for diamond growth in a chemical vapour deposition (CVD) reactor (the CVD reactor is not shown).

In this embodiment a 1.5 kW microwave CVD reactor (fabricated by AsTex) is used to grow diamond crystallites on the fibre end-faces (step 34).

After the sample is loaded inside the reactor chamber, the chamber is evacuated to a vacuum pressure (for example 10^{-3} Torr, and may be lower if required). The sample is heated using an induction heater. In this embodiment the chamber is filled with hydrogen, methane and nitrogen in ratios of, for example, 99% hydrogen, 0.7% methane and 0.3 % nitrogen. The chamber is brought up to

a pressure (for example 30 Torr) and the gases are then flowed through at this constant ratio and pressure. Microwaves are guided into the reactor chamber and excite the gases to form a plasma. Diamond then grows on the substrate located under or slightly in the plasma.

After the growth of diamond crystals on the waveguide end-faces the diamond crystals are embedded by splicing the respective end-faces with the end-faces of bare waveguides to form a virtually seamless strand of optical waveguide with a diamond crystal embedded in the waveguide core (step 36). Waveguide splicing may also be achieved using index matching glues or finger splicing devices.

The formed photon source is operated on a pulsed laser source, such as a pulsed 532 nm laser (step 38, the laser is not shown). On the output of the fibre, the pump frequency is filtered with an attenuation filter or grating. The laser pulses, once propagating along the fibre, require no further alignment with respect to the diamond because of the diamond's location on the fibre core. This incidental spatial filtering ensures the excitation only of the colour centre located in the core.

Figure 4 shows a photon source during fabrication according to another embodiment of the invention. Figure 4 shows an optical waveguide 40 (either optical fibre or planar waveguide) having a core 42 and a cladding 44. A recess 46 was etched into the core 42 from end-face 48. For example, the recess may be etched using a wet etching process. In this embodiment, an etching process is used that preferentially etches the core material so as to form the recess 46 in the core 42. In this example, the core 42 is composed of germanium doped silica and the cladding 44 is composed of silica. A 48% hydrofluoric acid solution is used to preferentially etch the core from end-face 48. As

the relative etch rates of core and cladding material are known, it is possible to control the depth of the recess 46.

A diamond crystal 49 is then grown within the recess 46. The inventors have observed that nucleation of the diamond material during CVD growth predominantly occurs at the or each edges such as edges of recess 46. Therefore, the recess in the core has the advantage that the diamond crystals predominantly grow at or near the core 46 when end-face 48 is exposed to the chemical vapour of the chemical vapour deposition. The end-face 48 is then fused to end-face 50 of another optical fibre 52 so that the recess forms a closed cavity in which the diamond crystal 49 is positioned. An efficient optical cavity may be formed be adding mirrors to each end of the cavity enclosing the diamond crystal. For example, the mirrors may comprise Bragg gratings at either end of the cavity.

As indicated above, the photon emission from colour centres typically is isotropic. However when the colour centre is embedded in a waveguide, the surrounding medium is not isotropic. Just as propagation of an optical signal along the core of an optical fibre is favoured over propagation transverse to the fibre, so too is propagation of photons emitted from the colour centre. This means that the spontaneous emission will be stronger in the direction of the waveguide (this enhancement is due to the Purcell effect). In this embodiment, the spontaneous photon emission in the direction of the core is further enhanced because the colour centre is positioned in the optical cavity formed by recess 46 and mirrors. In this embodiment, the optical cavity is elongated and mainly hollow and therefore increases the effective intensity of "empty space" along the core and hence increase the

spontaneous emission in a direction along the core. Such cavity enhancement is particularly advantageous for transform limited pulses or coherent photon pulses.

Figure 5 shows a quantum key distribution system according to an embodiment of the present invention. The system 60 comprises a pulsed laser source 61, a single photon source 62 and an electro-optic modulator for controlled polarisation of the emitted single photons. The single photon source 62 may be a photon source according to any one of the above-described embodiments. Optical fibre 64 connects the components and directs the single photons to lens 65. Beam splitter 66 directs 50% of the photons through quarter wavelength plate 67. From the quarter wavelength plate 67 the photons are directed though polarisation beam splitter 68 and the respective polarisation components are detected by respective detectors 70.

The other 50% of the photons that beamsplitter 66 separates are directed though another polarisation beam splitter 68 and the respective polarisation components are detected by further detectors 70. For general details about the operation of a quantum key distribution systems of the type shown in Figure 5 reference is made to A. Beveratos at al, Phys. Rev. Lett. 89, 187901 (2002).

Although the invention has been described with reference to particular examples, it will be appreciated by those skilled in the art that the invention may be embodied in many other forms. For example, the colour centres may not comprise nitrogen-vacancies but may for example comprise nickel and nitrogen atoms. For other examples of colour centres reference is made to "Optical Properties of Diamond", A Data Handbook, Zaitsev, A.M. 2001, XVII, ISBN: 3-540-66582-X Springer

Further, the material having the colour centre may not necessarily be diamond and may not be deposited on a portion of a waveguide. If diamond crystals are present, the crystals may be provided in form nano, micro, single, poly crystals. For example, the material may be deposited on a layer that is formed on the waveguide or may be formed elsewhere and mechanically coupled to the waveguide and embedded within the waveguide. Alternatively, the waveguide may also comprise a core that is formed from the material, such as diamond, and in which the or each colour centre is formed.

In addition it is to be appreciated that the material having the or each colour centre may also be mechanically be embedded in the waveguide. For example, a hole may be etched into the waveguide and the material may be inserted into the hole which may then be closed.

It is also to be appreciated that the photon source may be used for any application which requires such a photon source. This includes quantum key distribution but also includes other suitable applications such as applications in the area of research.

Further, it is to be appreciated that the reference that is being made to prior art publications does not constitute an admission that the publication forms a part of the common general knowledge in the art, in Australia or any other country.

The Claims defining the Invention are as Follows:

1. A photon source comprising:
an optical waveguide and
a material comprising at least one colour centre, the or each colour centre being arranged for emission of single photons and the material having been grown so that the material is bonded to the optical waveguide and in use at least some of the single photons emitted by the or each colour centre are guided by the optical waveguide.

2. A photon source comprising:
an optical waveguide incorporating a material having at least one colour centre arranged for emission of single photons, the material being incorporated so that in use at least some of the single photons emitted from the or each colour centre are guided by the optical waveguide.

3. The photon source as claimed in claim 1 or 2 wherein the material has a diamond structure.

4. The photon source as claimed in any one of the preceding claims wherein the material is a diamond material.

5. The photon source as claimed in any one of the preceding claims wherein the material is bonded to the waveguide.

6. The photon source as claimed in any one of the preceding claims wherein the material is grown on a portion of a core region of the waveguide.

7. The photon source as claimed in any one of the preceding claims wherein the material is a diamond crystal and the or each colour centre comprises a nitrogen atom adjacent to a vacancy in the diamond crystal lattice.

8. The photon source as claimed in any one of claims 1 to 6 wherein the material is a diamond crystal and the or each colour centre comprises a nickel atom adjacent to four vacancy in the diamond crystal lattice

9. The photon source as claimed in any one of the preceding claims being a source of single photons and comprising one colour centre for the emission of single photons.

10. The photon source as claimed in any one of the preceding claims wherein the waveguide is an optical fibre.

11. The photon source as claimed in any one of claims 1 to 9 wherein the waveguide is a planar waveguide.

12. The photon source as claimed in claim 10 or 11 comprising a core region that is surrounded by a core-surrounding region which has a lower refractive index that the core region.

13. The photon source as claimed in claim 10 or 11 comprising a number of light-confining elements arranged about the core region so that light can be guided in the core region.

14. The photon source as claimed in claim 13 wherein the

core region is solid and the light-confining elements result in an average refractive index of a core-surrounding region being lower than that of the core region.

15. The photon source as claimed in claim 13 wherein the light-confining elements are arranged so that a photonic crystal waveguide is formed having photonic bandgap in the core-surrounding region.

16. The photon source as claimed in any one of the proceeding claims wherein the material is positioned in a cavity which is located in the waveguide.

17. The photon source as claimed in claim 16 wherein the cavity is located in a core region of the waveguide.

18. The photon source as claimed in 16 or 17 wherein the cavity is an optical cavity.

19. The photon source as claimed in claim 2 or in any one of claims 3 to 18 when dependent on claim 2 wherein the material is embedded in the optical waveguide.

20. The photon source as claimed in claim 2 or in any one of claims 3 to 18 when dependent on claim 2 wherein the material forms a part of the waveguide.

21. The photon source as claimed in claim 2 or in any one of claims 3 to 18 when dependent on claim 2 wherein the waveguide has a diamond core that comprises the or each colour centre.

22. A method of fabricating a photon source comprising:
providing an optical waveguide and
growing a material on adjacent or in association with the optical waveguide in a manner so that at least one colour centre is formed in the material for emission of single photons.

23. The method as claimed in claim 22 wherein the material is grown in a manner such that the material and is bonded to the optical waveguide and in use at least some of the single photons emitted from the or each colour centre are guided by the optical waveguide.

24. The method as claimed in claim 23 wherein the material is grown directly on a portion of the waveguide so that a direct bonding of the optical waveguide with the material is effected.

25. The method as claimed in any one of claims 22 to 24 comprising the additional step of forming at least one recess in the optical waveguide.

26. The method as claimed in claim 25 wherein the waveguide comprises a core and a core surrounding region and the at least one recess is formed at an end-face of the waveguide in the core region.

27. The method as claimed in claim 25 or 26 wherein the recess is formed by etching the recess in the core region using an etch-process that preferentially etches material of the core region.

28. The method as claimed in any one of claims 22 to 27

wherein the material comprises diamond crystals having the or each colour centre.

29. The method as claimed in any one of claims 22 to 28 wherein the step of growing the material involves chemical vapour deposition (CVD).

30. The method as claimed in any one of claims 25 to 27 or any one of claims 28 to 29 when dependent on claim 25 wherein the step of growing a material comprises growing the material at an edge associated with the or each recess.

31. The method as claimed in any one of claims 25 to 27 or any one of claims 28 to 30 when dependent on claim 23 wherein the step of growing a material comprises growing the material in the or each recess.

32. The method as claimed in claim 31 wherein the material is grown at an end-face of the waveguide and the method comprises the step of splicing the end-face with an end-face of another waveguide.

33. The method as claimed in claim 31 wherein the material is grown at an end-face and in the or each recess and the method comprises the step of splicing the end-face with an end-face of another waveguide so that the or each recess is closed and forms a cavity comprising that material having the or each colour centre.

34. A method of fabricating a photon source comprising an optical waveguide, the method comprising the steps of:

fabricating an optical waveguide incorporating a material in which at least one colour centre for the emission of single photons can be formed and

forming the or each colour centre in the material in a manner so that in use at least some of the single photons emitted by the or each colour centre are guided by the optical waveguide.

35. The method as claimed in claim 34 wherein the material is embedded in another portion of the optical waveguide.

36. The method as claimed in claim 34 wherein the optical waveguide has a core and the material forms a part of the core.

37. The method as claimed in claim 34 wherein the optical waveguide has a core which is composed of the material.

38. A photon source fabricated by the method as claimed in any one of claims 22 to 37.

39. A quantum key distribution system comprising the photon source as claimed in any one of claims 1 to 20.

DATED this 3rd day of JUNE 2004
QUCOR PTY LTD

By their Patent Attorneys
GRIFFITH HACK

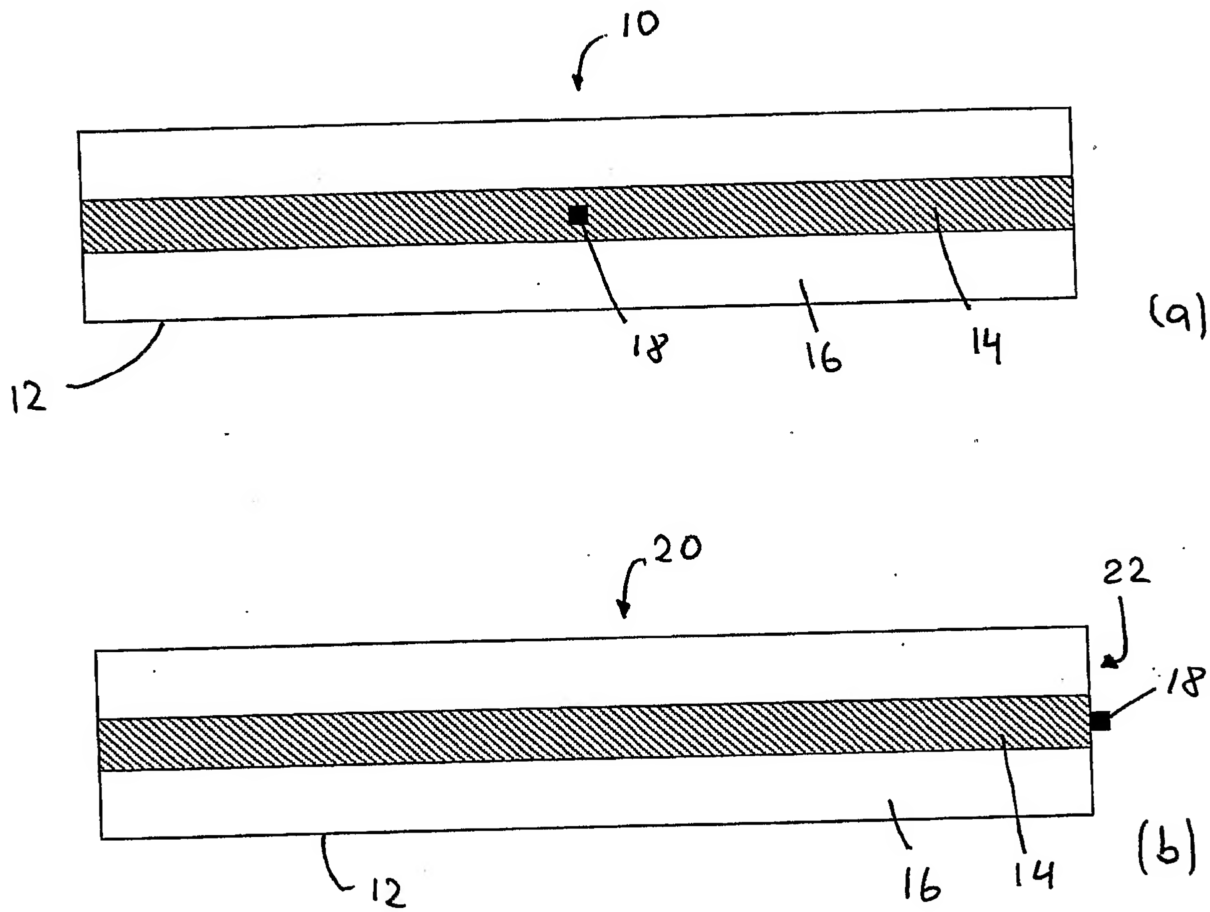
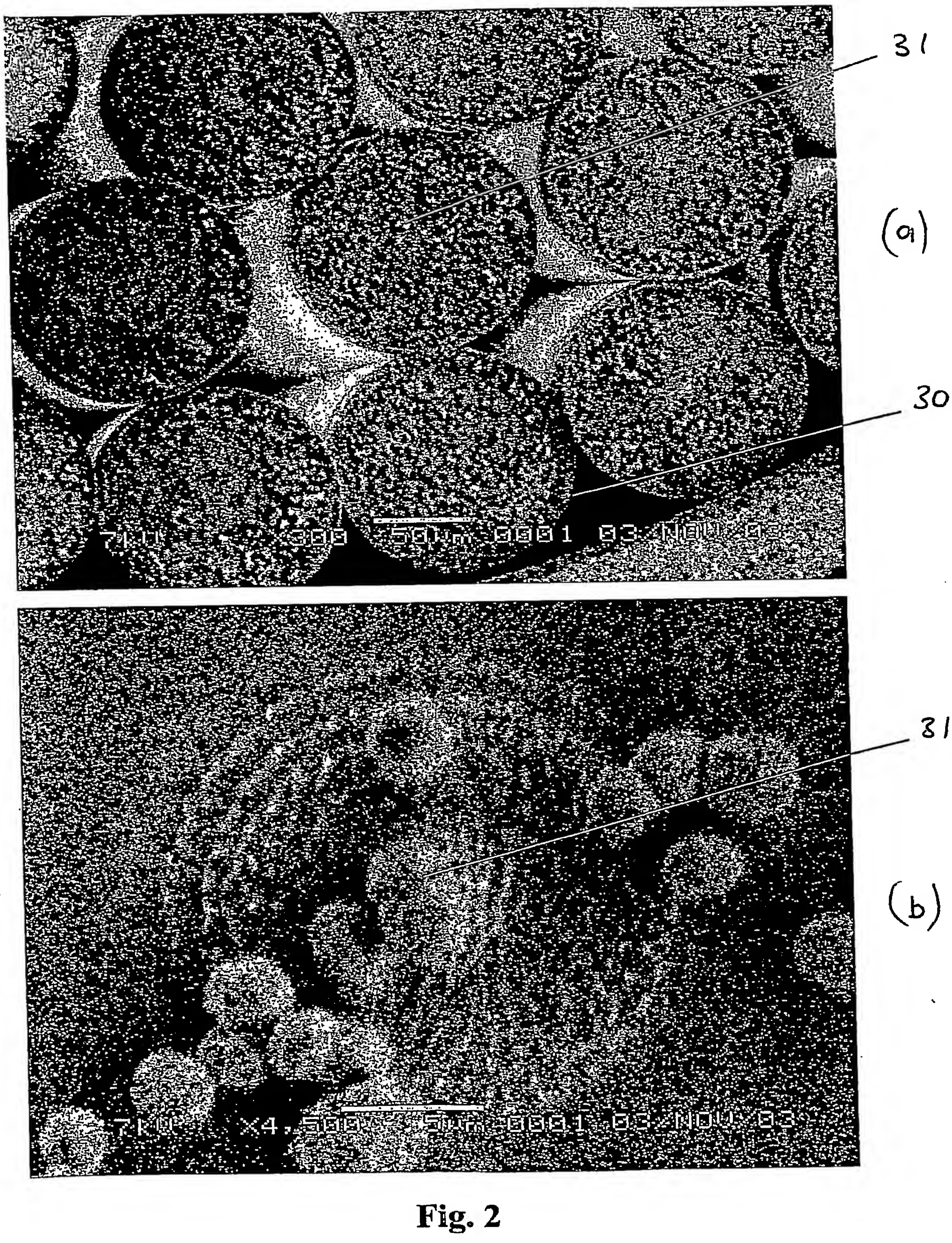
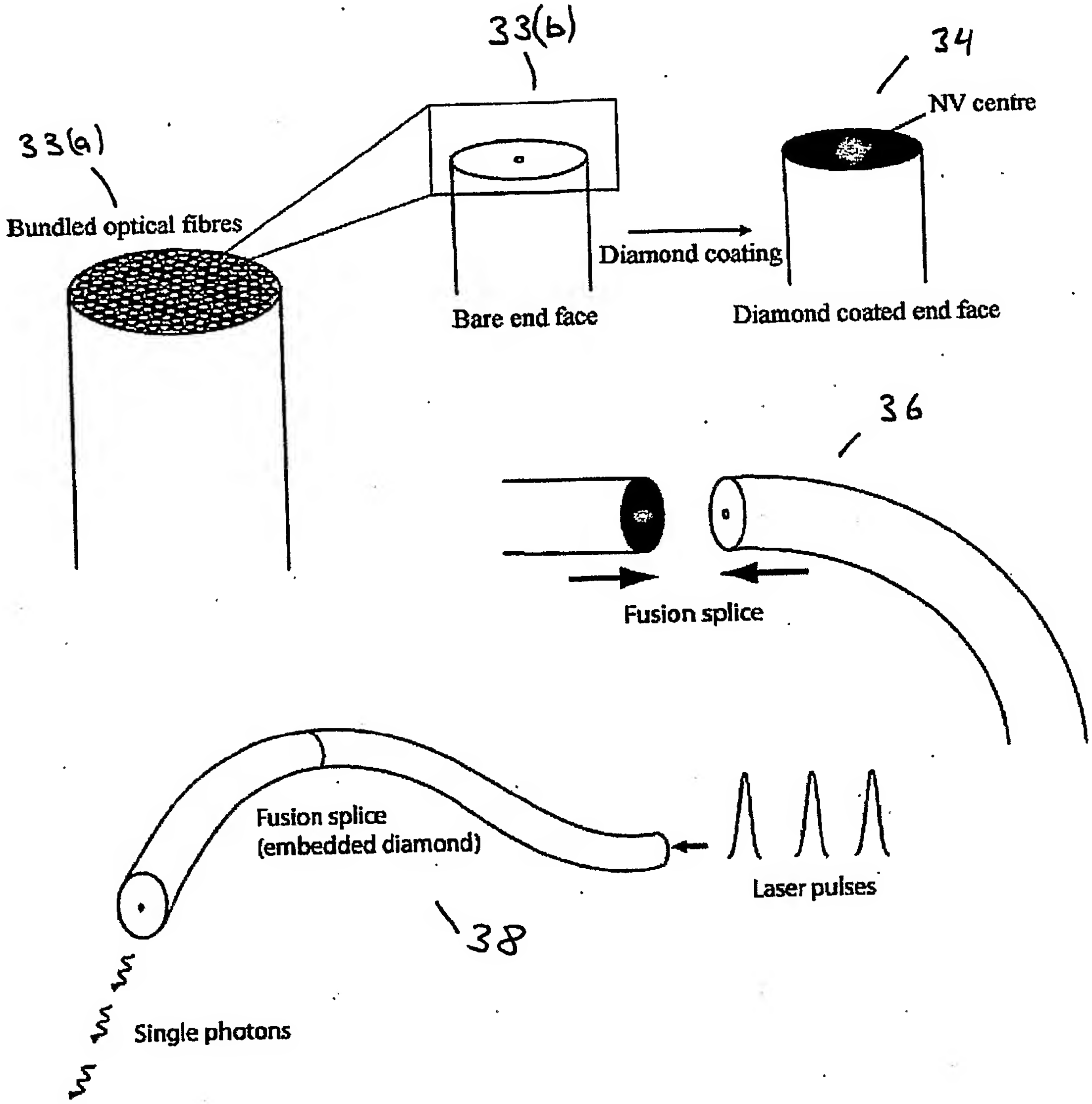


Fig. 1



31
(a)
30
7kV X300 50µm 0001 03 NOV 03
31
(b)
7kV X4,500 5µm 0001 03 NOV 03

Fig. 2



33(b)
34
NV centre
33(a)
Bundled optical fibres
Diamond coating
Bare end face
Diamond coated end face
36
Fusion splice
Fusion splice
(embedded diamond)
Laser pulses
38
Single photons

Fig. 3

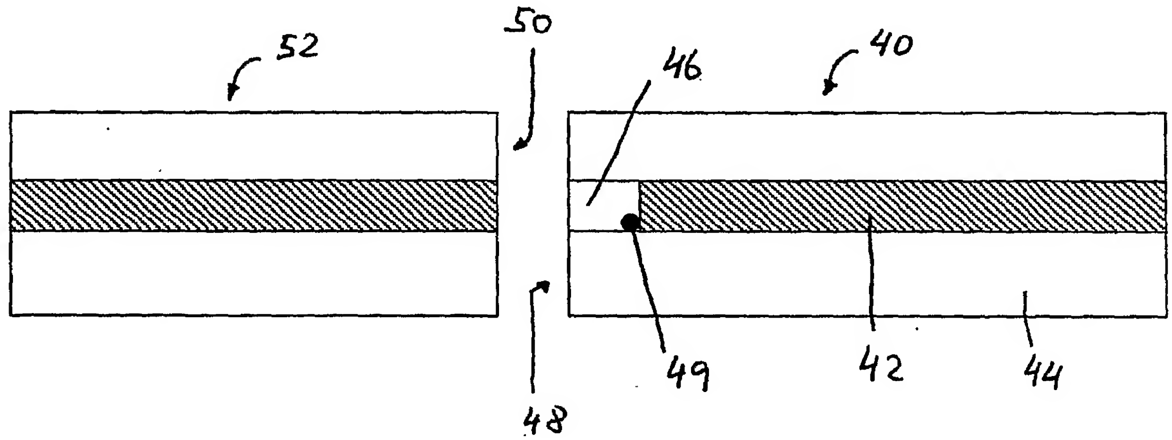


Fig. 4

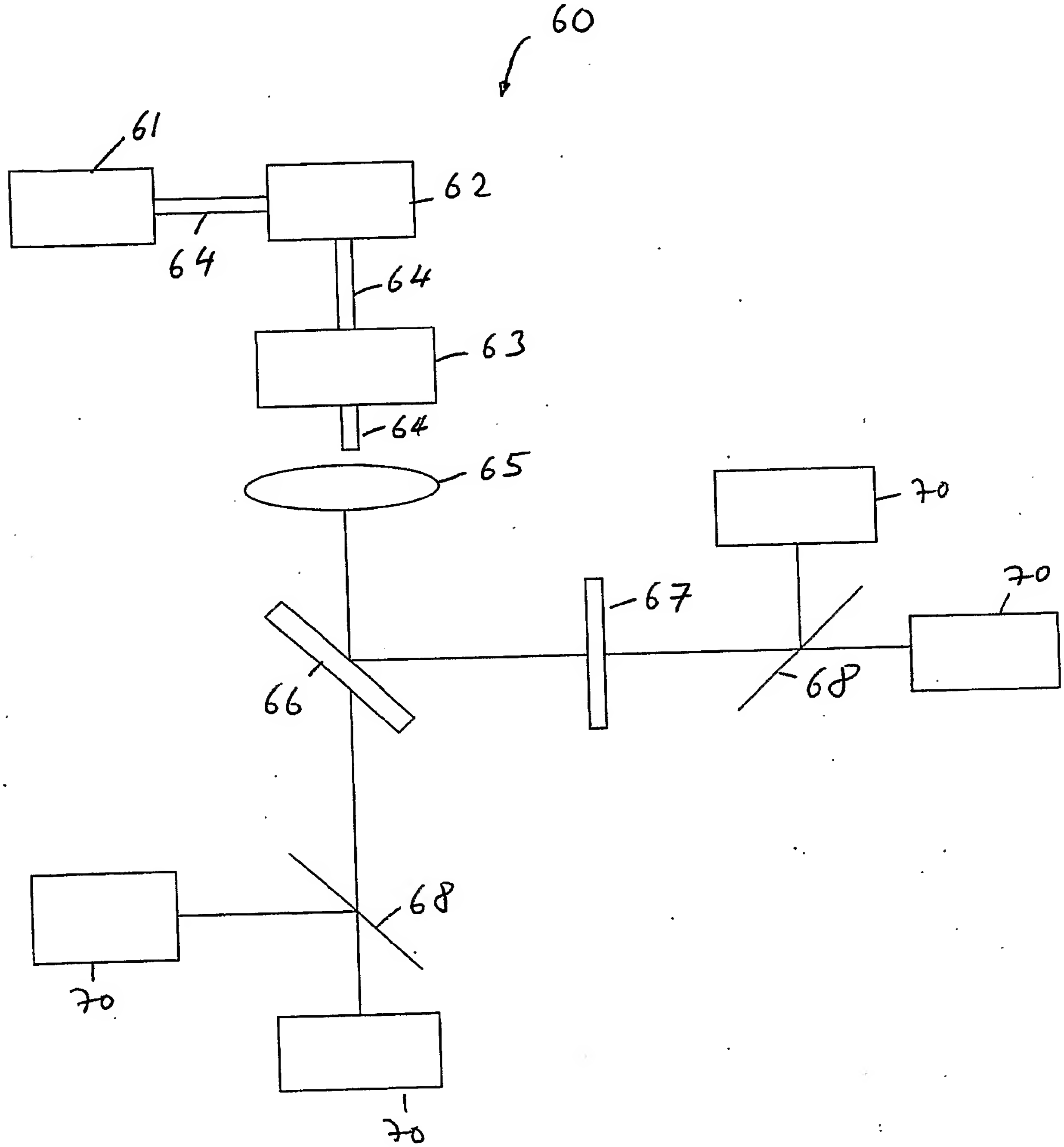


Fig. 5